Journal of Forestry Research (2011) 22(3): 379–385
DOI 10.1007/s11676-011-0182-8

ORIGINAL PAPER

Performance and variability patterns in wood properties and growth traits in the parents, F1 and F2 generation hybrid clones of *Populus deltoides*

P. K. Pande • R. C. Dhiman

Received: 2010-10-19; Accepted: 2010-12-02

Abstract: The performance and variability patterns in the wood element's dimensions, specific gravity and growth parameters namely ramet height and GBH were evaluated in 16 clones of parents, F1 and F2 hybrids of *Populus deltoides* Bartr. ex Marsh. Ramet radial variations were non-significant, while inter-clonal variations due to interaction of clone/replication were significant for all the wood traits except vessel element length. Inter-clonal variations were significant only for fiber length and fiber wall thickness. Fiber length and specific gravity were significantly higher in female, while wall thickness and vessel element length were higher in male clones. Female parents (G48 and S7C8) showed higher fiber length and specific gravity than of the male parent (G3), while vessel diameter and wall thickness were higher in male parent (G3). There is not much difference in fiber length and vessel element's dimensions among the parents, F1 and F2 generation hybrid clones. Specific gravity did not showed any trend for parents, F1 and F2 generations. Generally female clones showed higher growth rate. Broad sense heritability for wood traits ranged from 0.143 (fiber length) to 0.505 (fiber wall thickness), while for growth traits it was 0.374 (GBH) and 0.418 (height). Genetic gain for all the wood and growth traits was positive for most of the wood traits. The highly divergent male clone (78) and female clones (S7C8, G48, W/A 49) in number of combinations could be used for developing new hybrids of desired wood traits to develop new clones.

Keywords: Fiber length; specific gravity; vessel element length and wall thickness; wood variations

The online version is available at http://www.springerlink.com

P. K. Pande (✉)
Wood Anatomy Discipline, Botany Division, Forest Research Institute, Dehradun (India)-248006. E-mail: pandep123@rediffmail.com

R. C. Dhiman
WIMCO Seedlings Ltd., Rudrapur, Udhamsingh Nagar, Uttarakhand, India.

Responsible editor: Yu Lei

Introduction

Populus deltoides belongs to the family of Salicaceae. Out of six indigenous species and eight Indianized exotic species of *Populus*, *P. deltoides* is the commercially most important one. It is a multipurpose tree species and can be grown on short circle. The genus *Populus* with dioeciousness for its large number of hybrids/clones are propagated vegetatively and offer excellent opportunities for the improvement and selection. Thus, clones/hybrids/cultivars of *Populus* were developed all over the world. Open pollinated seeds from the promising clones of *P. deltoides* are already available in India, and seedling populations are generated for further selection of promising individual plants for cloning. In India a number of clones of *P. deltoides* have been developed and are grown commercially.

The variability in anatomical characteristics has profound influence on the wood properties (Dadswell 1957; Burley and Palmer 1979). Fiber and vessel element's dimensions, proportion and arrangements of different elements and specific gravity are the features of interest in this connection. The general pattern of variation in wood element dimensions is found not only within a species but also observed within a tree in different species (Dinowoodie 1961; Zobel 1965; Rao and Rao 1978; Pande et al. 1995; Pande and Dhiman 2010).

Variations in the dimensions of wood elements and specific gravity within ramet, inter-ramet and among the clones have come under close scrutiny in recent years. There are reports available on the variation in wood anatomical and other properties in different clones of *Populus* elsewhere (Phelps et al. 1982; Kauba et al. 1998; Chauhan et al. 1999, 2001). Radial and directional non-significant variations in specific gravity and fiber length in different clones of *Dalbergia sissoo* and *Eucalyptus tereticornis* was reported by Pande and Singh (2005, 2009); and related to early maturity of clone raised tree. Inter-tree variations in specific gravity of *D. sissoo* were also reported by Pande (2008) and in *Lucanea leucocephala* by Pande et al. (2008).

Similarly, significant differences among the different clones of different species in average fiber length were reported by many a worker (Murphey et al. 1979; Phelps et al. 1982; Chauhan et al. 1999 and 2001; Rao et al. 2002; Pande and Singh 2005). Inter-clonal variation in vessel element dimensions in *D. sissoo* was reported by Pande and Singh (2005), in *Populus deltoides* by Chauhan et al. (1999) and in *T. grandis* by Rao and Shashikala (2003). However, there is no available literature on the comparison and variations in the wood properties and growth performance among the clones of parents and successive generations.

The growth and the wood quality are two important parameters for the assessment of clones considering their end uses. The parameters *viz* wood elements dimensions, specific gravity and growth parameters namely GBH and height should be compared among the parents, F1 and F2 generation's plantations and the heritability patterns of selected wood and growth traits, so that the superior hybrids can be recommend for the further use.

In view of the above, the present study presents the comparison of the variability patterns in wood and growth traits among the parents, F1, F2 hybrid clones, and broad sense heritability of different wood, as well as growth traits and clustering of clones of parents and successive generations for the selection of divergent clones.

Materials and methods

The experimental site

Study site was located at Rudrapur (Udhamsing Nagar), Uttarakhand, India. It is situated at around 28° N, 78° E at elevation of 200 m asl. Annual precipitation is 1 200 mm, of which 88% occurs during June–August. The average maximum summer temperature (April–June) is 36.7°C and average minimum temperature (December–February) is 7.5°C (2005–2006). The soil of the site is sandy loam.

Planting material

The growth parameters such as ramet height and GBH were measured for each individual ramet before the collection of wood material. Study material was collected from the 16 clones of *Populus deltoids* raised by WIMCO Plantations Ltd. at Rudrapur (Udhamsingh Nagar), India. Three clones were parent *viz.* G48, S7C8 (female) and G3 (male). Other clones represent hybrids of F1 and F2 generation. The year of plantation was February, 2000, and we collected samples in October, 2007. The soil of the plantation site was sandy loam. The clones were raised in Randomized Block Design, with spacing of clonal trial 5 m × 5 m. The details of clones are shown in Table 1.

Sampling

Wooden cores were extracted from three replicate ramets of 16 individual clones at 3.17 m height from the base from the north direction. Each core was divided into three piths to periphery locations *viz*. inner, middle and outer. In total 144 wood samples were collected for anatomical study including fiber length, fiber diameter, wall thickness, vessel element length, vessel element diameter, and specific gravity. Standard laboratory methods were followed for the preparation of macerations. Wooden cores were fragmented into small pieces and put into the test tube. The material was macerated with 50% HNO_3 and a pinch of $KClO_3$. The macerated wood elements were thoroughly mixed and were spread on a glass slide, and observations were taken under compound microscope (Purkayastha et al. 1980). Measurements for fiber length, fiber diameter, wall thickness, vessel element length and vessel element diameter were taken from the macerated wood. Twenty-five unbroken cells were sampled for the measurement of each parameter (IAWA Committee 1989). Basic density of core samples was determined by the ratio of oven dry weight and green volume. The green volume was determined by water displacement method. Specific gravity was the ratio of the density of the core sample and density of water (Purkayastha et al. 1980).

Table 1. The details of different clones

S. No.	Clone	Parents	Sex	Generation
1	G48	Parents	F	P
2	S7C8	Parents	F	P
3	G3	Parents	M	P
4	Kranti	G48*G3	F	F1
5	W-A/49	G48*G3	F	F1
6	102	S7C8*G3	F	F1
7	Cp82-5-1	S7C8*G3	M	F1
8	104	S7C8*G3	M	F1
9	66	G48*G3	M	F1
10	61	Kranti * G3	F	F2
11	22	W-A/49*G3	F	F2
12	62	Kranti * G3	F	F2
13	14	Kranti * CP-82-5-1	F	F2
14	79	W-A/49*CP-82-5-1	M	F2
15	78	W-A/49*CP-82-5-1	M	F2
16	52	Kranti*G3	M	F2

Statistical analysis

The data were statistically analyzed by using SPSS 10. Multivariate analysis was done to test the ramet radial, inter and inter-clonal variations. The genotype and phenotype components of variance were calculated from the ANOVA (Burton 1952).

Genotype variance:

$$(\sigma^2 g) = (\sigma^2 e + R\sigma^2 c) - (\sigma^2 e)/r \quad (r\text{=replication}) \quad (1)$$

Phenotype variance:

$$(\sigma^2 p) = \sigma^2 g + \sigma^2 e \quad (2)$$

Genotypic Coefficient of variance:

$$GCV = (\sqrt{\sigma^2 g / \text{mean}}) \times 100 \quad (3)$$

Phenotypic coefficient of variance:

$$PCV = (\sqrt{\sigma^2 p / \text{mean}}) \times 100 \quad (4)$$

Heritability: Broad sense heritability was calculated as per Lush (1949).

$$h^2 = \sigma^2 g / \sigma^2 p \quad (5)$$

Genetic advance: Genetic advance was calculated as per described by Johnson et al. (1955).

$$Gs = Kh^2 \cdot \sqrt{\sigma^2 p} \quad (K=2.66) \quad (6)$$

$$\text{Genetic gain} = (Gs / mean) \times 100 \quad (7)$$

Hierarchical cluster analysis was done by SPSS 10 for wood anatomical properties, specific gravity and growth parameters such as GBH and height combined with "Squared Euclidean Distance" method. The hierarchical grouping develops a relationship between clones that are maximally similar for specified traits. Each of the clones is genetically different from another. However, the extent of difference might be varying to a certain degree. Thus, during clustering number of clones may vary from one to the total number of clones. To optimize the number of cluster, a cut of line was derived on the dendrogram that was close to half of the value. Four numbers of clusters were developed based on the information.

Result and discussion

The details of 16 selected clones of parents, F1 and F2 generations are shown in Table 1. The details of wood element's dimensions, specific gravity and growth parameters of different clones are shown in Table 2. The range for fiber length for different progenies was 968 (104, M, F1) – 1 162 μm (G48, F, P); 22.11 (104, M, F1) – 28.11 μm (G3, M, P) for fiber diameter; 3.53 (66, M, F1) – 5.04 (G3, M, P) μm for wall thickness; 532 (W/A 49) – 561.33 (14) μm for vessel element length; 96.11 (G48, F, P) – 108.56 μm (102, F, F1) for vessel element diameter; 0.326 (66, M, F1) – 0.423 (G48, F, P) for specific gravity. The average height of the clone ranged from 15.3 (14) to 23.0 (W/A 49) m while GBH ranged from 17.43 (Cp82-5-1, 14) to 27.80 cm (W/A49).

Table 2. Wood and growth traits of different clones of *Populus deltoides*

Clone	Sex	FL	SD	FD	SD	WT	SD	VL	SD	VD	SD	SG	GBH (cm)	Height (m)
S7C8	F	1140.0	161.00	25.67	4.32	4.47	0.92	560.22	125.78	103.11	26.33	0.368	23.37	16.07
G48	F	1161.8	169.78	25.78	4.41	4.48	1.07	552.56	113.89	96.11	20.78	0.423	23.33	16.6
Kranti	F	1048.8	145.78	27.89	4.30	4.77	0.92	560.22	101.22	104.44	19.89	0.333	24.00	16.5
W/A 49	F	1142.3	116.44	23.67	2.29	3.77	0.34	532.78	84.56	99.67	15.67	0.406	27.80	23.0
102	F	1085.3	147.00	23.78	4.31	3.74	0.87	559.44	97.67	108.56	24.44	0.346	19.20	19.7
61	F	986.7	172.44	23.22	4.69	4.11	0.97	574.44	121.22	101.44	18.33	0.355	22.63	22.6
22	F	1018.9	189.11	22.44	4.29	3.77	0.97	556.11	133.89	98.89	22.00	0.348	22.40	21.1
62	F	1000.6	162.00	23.67	4.69	3.86	0.97	567.22	115.44	106.22	25.22	0.338	19.80	20.7
14	F	1041.7	147.11	23.56	4.33	3.76	0.96	561.33	99.56	108.00	22.00	0.347	17.60	15.3
G3	M	1048.2	201.11	28.11	5.38	5.04	1.36	559.44	142.33	108.44	31.22	0.366	17.43	15.9
Cp82-5-1	M	1049.0	160.22	23.33	4.28	4.17	1.11	558.22	115.67	105.11	29.56	0.350	17.43	15.93
104	M	968.6	170.22	22.11	4.11	3.72	0.92	562.78	137.67	98.44	22.11	0.377	20.20	21.5
66	M	1033.1	150.22	23.33	4.34	3.53	0.74	554.00	104.89	108.44	27.44	0.326	22.60	22.6
79	M	1077.6	144.00	24.11	4.44	3.77	0.93	550.78	109.56	105.56	23.33	0.351	23.17	22.2
78	M	1053.6	159.89	23.89	4.39	3.91	1.00	544.67	108.89	102.78	19.78	0.335	26.63	21.9
52	M	1070.0	150.44	24.22	4.61	3.72	0.94	565.33	109.00	105.22	23.11	0.345	20.90	21.4

Note: FL--- fiber length, FD---fiber diameter, WT---wall thickness, VL---vessel element length, VD--vessel element diameter, SG--- specific gravity

Multivariate analysis of wood anatomical variations in different clones of *P. deltoids* is shown in Table 3. Within ramet radial variations were not significant for all the wood traits. Inter-clonal variations were significant for all the wood traits except for vessel element length, while inter-clonal variations were significant for fiber length and fiber wall thickness. Interaction of clone/replication was also significant for all the wood traits except for vessel element length, indicating significant genotype x environment interaction occurred within and among the clones. Non-significant inter-clonal variation in specific gravity and vessel element's dimension in the present study is indicative of genetic stability of these traits within the clone. Further, significant inter-clonal variations in fiber length and wall thickness may be attributed to the nature of juvenile wood and controlled by a combination of physiological and environmental factors (Kauba et al. 1998). Significant differences in average specific gravity of different clones from different species of *Populus* were reported (Chauhan et al. 1999; Phelps et al. 1982), as well as *T. grandis* (Okuyama et al. 2003) *E. tereticornis* Sm. (Rao et al. 2002; Pande 2005). Specific gravity is moderate to strongly inherited trait, and is under the influence of additive gene as in case of *T. grandis* (Mandal and Chauaan 2003), which is also in

accordance with the present study, where clone to clone variations were significant for this trait. Inter-tree variations in specific gravity were also reported by Pande (2008) in *Dalbergia sissoo* and in *Leucanaea leucocephala* by Pande et al. (2008). These inter-tree variations in specific gravity were related to the genetic entity of individual trees of seed raised progenies. Similarly, significant differences among the different clones of different species in average fiber length were reported by many researchers (Murphey et al. 1979; Phelps et al. 1982; Chauhan et al. 1999 and 2001; Rao et al. 2002; Pande and Singh 2005). Inter-clonal variation in fiber and vessel element dimensions in *D. sissoo* was reported by Pande and Singh (2005), and in *Populus deltoides* by Chauhan et al. (1999) and in *T. grandis* by Rao and Shashikala (2003). The clone to clone variations for wood traits are indicative of the individual genetic entity for the wood traits of the different clones of different species. Gautam (2010) reported inter-clonal variations in L-34 clone of *P. deltoids* and indicated that differential wood properties may be expected from the ramets of the same clone. This is in agreement with the present study. Within ramet radial variations were significant for specific gravity with the increasing trend from pith to periphery, according to the age of the wood (Gautam 2010). Though the radial variations were non-significant for all wood traits, the increasing trend from pith to periphery for fiber length and specific gravity was noticed in the present study. The reason may be related to the age of the wood. Most reports on radial patterns in hardwoods described the fiber length and specific gravity. The fibers are shorter, and specific gravity is less near the center of the tree (Zobel and Buijtenen 1989). The pattern in *Populus* was also reported by Jayme et al. (1943) and Boyce and Kaiser (1961) and in *Eucalyptus* by Bisset and Dadswell (1949). Some other genera like *Fagus, Quercus* and *Fraxinus* continuously increased in fiber length for 40 to 100 years in seed raised trees depending on the species (Zobel and Buijtenen 1989). In some clonal plantations of *D. sissoo* and *E. tereticornis*, centre to outwards and bottom to top within ramet variations in wood element's dimensions and specific gravity were not-significant. The non-significant variations in wood element's dimensions and specific gravity were related to the early maturity of the wood in clone raised ramets. The early maturity of the wood in clonal plantations is due to carrying over of the physiological age of the ramet from the parent tree for the wood traits. Wood element's dimensions were also non-significantly varied in L-34 clone of *P. deltoides* form bottom to top and pith to outwards (Gautam 2010). It showed no age impact on the dimensions of wood elements and regulating mostly homogeneous wood properties within the ramet (Pande 2005; Pande & Singh 2009; Veenin et al. 2005). The same result is also true in the present study.

Fiber length and specific gravity are significantly higher in female, while wall thickness and vessel element length are significant higher in male clones (p<0.01). Female parents (G48 and S7C8) showed higher fiber length and specific gravity than the male parent (G3), while vessel diameter and wall thickness were higher in male parent (G3). Generally there is not much difference in fiber length and vessel element's dimensions among the parents, F1 and F2 generation clones. Fiber diameter and fiber wall thickness are higher in male parent than those of female parents and clones of F1 and F2 generations leaving few exceptions. There was no pattern for specific gravity among the parents, F1 and F2 generation clones. Generally female clones showed higher values for growth traits (Table 2).

Table 3. Multivariate analysis of different clones

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Clone	FL	363042.7	15	24202.85	8.088	0.000
	FD	384.8	15	25.65	13.614	0.000
	WT	23.7	15	1.58	21.325	0.000
	VL	26901.9	15	1793.46	1.358	0.185
	VD	2826.19	15	188.41	3.699	0.000
	SG	8.825E-02	15	5.883E-03	6.104	0.000
Replication	FL	32675.68	2	16337.84	5.460	0.006
	FD	17.38	2	8.69	4.613	0.012
	WT	2.30	2	1.15	15.494	0.000
	VL	4259.38	2	2129.69	1.613	0.205
	VD	30.43	2	15.21	.299	0.742
	SG	8.923E-03	2	4.461E-03	4.629	0.012
Location	FL	4669.597	2	2334.79	.780	0.461
	FD	4.84	2	2.42	1.286	0.281
	WT	0.229	2	0.115	1.545	0.219
	VL	1720.09	2	860.04	.651	0.524
	VD	270.39	2	135.19	2.654	0.076
	SG	2.505E-03	2	1.252E-03	1.299	0.278
Clone * replication	FL	483828.76	30	16127.62	5.389	0.000
	FD	298.39	30	9.94	5.278	0.000
	WT	11.68	30	0.389	5.245	0.000
	VL	54481.944	30	1816.065	1.375	0.125
	VD	3105.347	30	103.512	2.032	0.005
	SG	7.795E-02	30	2.598E-03	2.696	0.000
Error	FL	281295.736	94	2992.508		
	FD	177.153	94	1.885		
	WT	6.977	94	7.423E-02		
	VL	124107.903	94	1320.297		
	VD	4787.611	94	50.932		
	SG	9.061E-02	94	9.639E-04		

Note: FL--- fiber length, FD---fiber diameter, WT---wall thickness, VL---vessel element length, VD--vessel element diameter, SG---specific gravity

The genetic parameters like total genetic variations and genetic control for a particular trait are important tools to predict the amount of gain expected from the genetic material (Foster and Shaw 1988; Kumar 2007). Estimates of genetic parameters such as variance (both genotypic and phenotypic), broad sense heritability, genetic gain and genetic advancement for wood and growth traits are presented in Table 4. Heritability expresses the degree to which a character is influenced by genes as compared to environment. Broad sense heritability for wood traits ranged from 0.143 (fiber length) to 0.505 (fiber wall thickness), while for growth traits it was 0.374 (GBH) and 0.418 (height), and are

in agreement with the results of Nelson and Tauer (1987) for poplars as well as Kumar (2007) for *Gmelina arborea.* Fiber wall thickness and specific gravity were two important wood traits showing 0.515 and 0.297 broad sense heritability. The heritability values reported for different species of *Populus* were in the range of 0.56–0.70 (Farmer and Wilcox 1966; Farmer and Wilcox 1968; Reck 1974; Nepveu et al. 1978) for specific gravity. The heritability values for fiber length for *P. deltoides* was reported as 0.36 (Farmer and Wilcox 1968), and the value for *Populus polyploids* was 0.50 (Einspahr et al. 1963) and for *Populus trichocarpa* was 0.71 (Reck 1974). The values of heritability in the present study were lower than those of the above reported values. Though, evidences on heritability for hardwoods are somewhat scant, those studies indicate that there is moderate genetic control of cell length (Zobel and Buijtenen 1989). Heritability values express the proportion of variation in the clones which is attributed by the genetic differences among the clones. Genetic advance indicates average improvement in the offspring over the parents. In the study, genetic advance was higher for fiber length (29.49) and lowest for specific gravity (0.03). For growth parameters it was 3.63 and 1.55 for GBH and height respectively. Genetic gain (%) was higher for fiber diameter (8.57) followed by specific gravity (7.84), wall thickness (4.75), vessel element diameter (3.75), and fiber length (2.79) for the wood traits, while for growth traits it was 16.63 and 7.72, respectively, for GBH and height. Genetic gain for all the wood and growth traits was positive particularly for most important wood trait like specific gravity, wall thickness and growth trait like GBH.

Table 4. Estimates of genetic parameters 16 clones of *Populus deltoides*

Character	Mean	Genotype variance	Phenotype variance	Broad sense heritability	Genotypic coefficient of variance	Phenotypic coefficient of variance	Genetic advance	Genetic gain (%)
FL	1056.3	897.25	6273.12	0.143	2.84	7.5	29.49	2.79
FD	24.1	1.75	5.06	0.345	5.48	9.35	2.07	8.57
WT	3.99	0.13	0.26	0.505	9.14	13.73	0.19	4.75
VD	103.5	9.43	43.94	0.215	2.97	6.4	3.78	3.65
SG	0.356	0.0004	0.0012	0.297	6.27	9.82	0.028	7.84
GBH	21.8	4.97	13.30	0.374	16.71	16.71	3.63	16.63
Height	20.09	4.99	11.94	0.418	11.12	17.2	1.55	7.72

FL--- fiber length, FD---fiber diameter, WT---wall thickness, VD--vessel element diameter, SG--- specific gravity

Hierarchical cluster analysis was conducted by using "Squared Euclidean Distance" for all the 16 clones considering all the wood and growth traits. Dendrogram was prepared using Average Linkage (between groups). In the study, 16 clones were grouped into 4 clusters at 12.5 rescaled distance cluster combine (Figure 1). The constituents of different clusters were given in Table 5. Cluster 1 was the largest clusters with 9 clones, whereas, cluster numbers 2 has only one clone. Cluster 4 was the highly divergent from other clusters with the S7C8, G48 (parents) and W/A 49 (F1) all female clones.

Table 5. Constitution of different clusters

Cluster Number	No. of clones in the cluster	Clone number and sex
1	9	22 , 14, Kranti (F) 102, 66, G3, Cp82-5-1, 79, 52 (M)
2	1	78 (M)
3	3	61, 62 (F), 104 (M)
4	3	S7C8, G48, W/A 49 (F)

The mean values of different wood traits for different clusters are given in Table 6. Cluster 4 showed higher values for wood traits *viz.* fiber dimensions and specific gravity, while lower values for fiber dimensions were represented by cluster 3 and for specific gravity by cluster 1. Growth parameters *viz.* GBH and height were higher in single clone cluster 2. Vessel element's dimensions were higher in cluster 1, whereas, lower values were represented by cluster 4.

Table 6. Mean value of wood element's dimensions (μm), specific gravity and growth parameters

Cluster Number	FL	FD	WT	VL	VD	SG	GBH (cm)	Height (m)
1	1052.5	24.5	4.0	558.3	105.9	0.300	20.5	19.0
2	1053.6	23.89	3.91	544.67	102.78	0.335	26.63	21.9
3	985.3	23.00	3.90	568.15	102.04	0.357	20.88	21.62
4	1148.0	25.04	4.24	548.52	99.63	0.399	24.83	18.56

Note: FL---fiber length, FD---fiber diameter, WT---wall thickness, VL---vessel element length, VD--vessel element diameter, SG---specific gravity

Of all the wood properties, specific gravity and fiber dimensions are important wood traits, because they have strong relationship with both the yield and the quality. Therefore, they are recommended secondary traits, and tree improvement programs are taking this route (Zobel and Buijtenen 1989). Genetic divergence is the most effective tool to identify the parents for hybridization (Bhatt 1973). Selection for both female and male parents from two divergent clusters is important to develop hybrids for new clones. Clusters 2 and 4 were the divergent clusters for male and female clones respectively. Cluster 2 has one male

clone i.e. 78 clones, which are highly divergent from the clones, clustered in cluster 1 at 10 rescaled distance cluster combine. In the same way, cluster 5 has three female clones *viz*. S7C8, G48 (parents) W/A 49 of F1 (G48*G3), which are divergent from the other clusters at 25 rescaled distance cluster combine. Since clones in cluster 2 and 4 were highly divergent from other clones, these clones can be used for establishing clonal seed orchard for immediate gain in view of their high diversity.

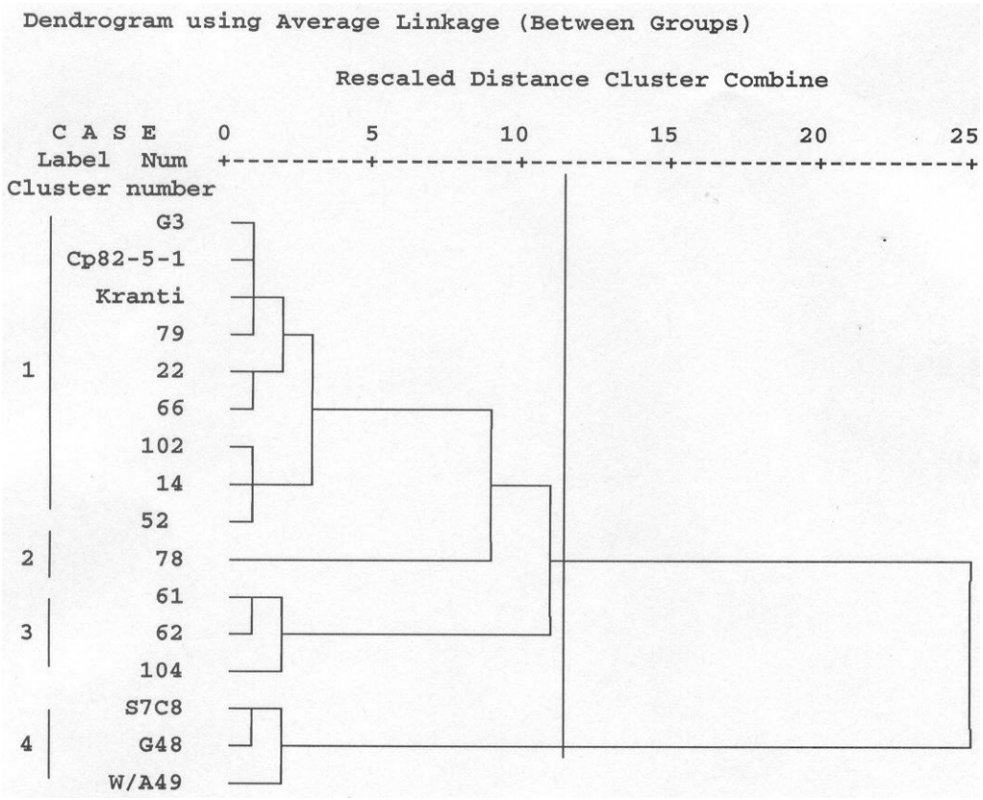

Fig. 1 Dendrogram using average linkage for the different *Populus deltoides* clones

Though clonal strategy is alleged to offer narrow genetic base, vegetative propagation has strongly recommended (Camphinhos and Ikemori 1980; Ahuja and Libby 1993a and 1993b). *P. deltoides* is propagated through clones. So development/selection of new clones in view of their desired wood properties is utmost important for the products. In this study, the highly divergent male clone 78, and female clones S7C8, G48 (parents) and W/A 49 (G48*G3; F1 hybrid) are important and should be used in number of combinations for developing new hybrids of desired wood traits to develop new clones.

Acknowledgements

We acknowledge to the Director, Forest Research Institute, Dehradun (India) for providing necessary facilities during the work. We are also thankful to Mr. Kishan Kumar, Wood anatomy Discipline, Forest Research Institute, Dehradun (India) for laboratory-assistance and Mr. J N Gandhi of WIMCO Seedlings Ltd. Rudrapur (India) for field assistance.

References

Ahuja MR, Libby WJ. 1993a. *Clonal forestry I: genetics and biotechnology*. New York: Springer-Verlag, p. 227.

Ahuja MR, Libby WJ. 1993b. *Clonal forestry II: genetics and biotechnology*. New York: Springer-Verlag, p. 240.

Bhatt GM. 1973. Comparison of various methods of selecting parents for hybridization in common bread wheat (*Triticum aestivum*). *Australian Journal Agriculture Research*, **24**: 457–484.

Boyce SG, Kaiser M. 1961. Environmental and genetic variability in the length of fibers of eastern cottonwood. *Tappi*, **44**: 363–366.

Burley J, Palmer RR. 1979. Pulp and wood densitometric properties of *Pinus caribaea* from Fiji. *CFI Occasional Paper*, p. 66

Burton GW. 1952. Quantitative inheritance in grass. In 6th International Grassland Congress. Part I: 277–283.

Camphinhos E, Ikemori YK. 1980. Mass production of *Eucalyptus* species by rooting cuttings. Sao Pede Sao Paulo: In proceedings IUFRO Symp. Genetic. improvement and production of fast growing trees, p. 16.

Chauhan L, Raturi RD, Gupta S. 1999. Studies on anatomical variations in different clones of *Populus deltoides*. *Indian Forester*, **125**: 526–532.

Chauhan L, Gupta S, Madhwal RC, Pandey R, Pal M. 2001. Interclonal, intraclonal and within tree variation in wood parameters of different clones of *Populus deltoides*. *Indian Forester*, **127** (7): 777–784.

Dadswell HE. 1957. Tree growth characteristics and their influence on wood structure and properties. In: Proceedings of 7th British Commonwealth Forestry Conference, CSIRO. Australia, p. 19.

Dinwoodie JM. 1961. Tracheid and fiber-length in timber: a review of literature. *Forestry*, **34**: 124–144.

Einspahr DW, Van Buijtenen JP, Peckham JR. 1963. Natural variation and heritability in triploid aspen. *Silvae Genet*, **12**(2): 51−58.

Farmer RE, Wilcox JR. 1966. Variation in juvenile growth and wood properties in half-sib cottonwood families. In: Joint Proceedings of the Second Genetics Workshop of the Society of American Foresters and the Seventh Lake States Forest Tree Improvement Conference; Res. Pap. NC-6. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, p.1–4.

Farmer RE, Wilcox JR. 1968. Preliminary testing of eastern cottonwood clones. *TAG Theoretical and Applied Genetics*, **38**(6): 197–201.

Foster GS, Shaw DV. 1988. Using clonal replicates to explore genetic variation in perennial plant species. *TAG Theoretical and Applied Genetics*, **76**(5): 788−794.

Gautam P. 2010. Multilocational trials of micro-propagated l-34 clone of *Populus deltoides* Bartr. ex Marsh: analysis of wood anatomical properties and growth. Thesis submitted to the Forest Research Institute University, Dehradun, Uttarakhand (India).

Jayme G, Branscheld F, Harders–Steinhluser M, Eser L. 1943. Eignungsvergleich verchiedener Schwarzpappelholzer zur Zellstoffgewinnung. *Holz Roh-Werkst*, **21**: 14−19.

IAWA Committee. 1989. List of microscopic features for hardwood identification. IAWA Bull. n. s. 10: 201−332

Kaubaa A, Hernandez AE, Beaudoin M, Poliquin J. 1998. Interclonal, intra-clonal and within tree variationin fiber-length of Popular hybrid clones. *Wood and Fiber Science*, **30**(1): 140−147.

Kumar A. 2000. Genetic divergence studies in clonal performance of *Casuarina equisetifolia. Silvae Genetica*, **49**(2): 57−60.

Mandal AK, Chawaan PH. 2003. Investigations on inheritance of growth and wood properties and their inter-relationship in teak. In: International Conference on Quality timber products of teak from sustainable forest management (abstracts), 2-5 December 2003, KFRI, Kerala, India, p. 56.

Murphey WK, Bowersox TW, Blankenhorn PR. 1979. Selected wood properties of young *Populus* hybrid. *Wood Science*, **11**(4): 236–267.

Nelson CD, Tauer CG. 1987. Genetic variation in juvenile characteristics of *Populus deltoides* from Southern Great Plains. *Silvae Genet*, **36**: 216–221.

Nepveu G, Keller R, Tessier du Cros E. 1978. Selection of juvenile pur la qualite du bois chez certains peuplier noirs. *Ann Sci For*, **35**(1): 69–72.

Okuyama T, Yamamoto H, Wahyudi I, Hadi YS, Bhat KM. 2003. Some wood quality issues in planted teak. In: International conference on quality timber products of teak from sustainable forest management, 2-5 December 2003, KFRI, Kerala, India (abstracts). p. 21.

Pande PK. 2005. Assessment of the performance of different clones of *Dalbergia sissoo* and *Eucalyptus tereticornis* on the basis of wood quality under different farm forestry programs. Final Technical Report, ICFRE, Dehradun (India).

Pande PK. 2008. Assessment of the wood quality parameter in seed raised plantations of different diameter classes of *Dalbergia sissoo* Roxb. FRI-299/Bot-45, FTR submitted to ICFRE, pp. 120−126.

Pande PK, Dhiman RC. 2010. Variations in wood tratis in micro and macro propagated plantation woods of *Populus deltoides* Bartr. ex Marsh. *Advances in Biosciences and Biotechnology*, **1**(4): 263−275.

Pande PK, Naithani S, Kothiyal V, Mohanta SS, Juyal N, Rawat R. 2008. Intra and inter tree variations in physico-chemical and wood anatomical properties of *Leucaena leucocephala* (Lam.) de wit. *Indian Forester*, **134**(5): 622−632.

Pande PK, Rao RV, Agrawal SP, Singh M. 1995. Variation in the dimensions of trachied elements of *Pinus caribaea* var. *bahamensis*. *Journal of Tropical Forest Products,* **1**(2): 117−123.

Pande PK, Singh M. 2005. Intraclonal, inter-clonal and single tree variations of wood anatomical properties and specific gravity of clonal ramets of *Dalbergia sissoo* Roxb. *Wood Science and Technology*, **39**(5): 351−366.

Pande Pande PK and Singh M. 2009. Individual tree, intra- and inter-clonal variations in wood properties of the clonal ramets of *Eucalyptus tereticornis* Sm. *Indian Forester,* **135** (5):629-646.

Phelps JE, Isebrands JG, Jowett D. 1982. Raw material quality of short rotation intensively cultured *Populus* clones. *IAWA Bulletin n.s.*, **3**(3&4): 193−200.

Purkayastha SK, Agrawal SP, Farooqui P, Tandon RD, Chauhan L, Misra N. 1980. Evaluation of wood quality of Eucalyptus plantations in various states. Final Technical Report (Nov. 1 to Oct. 31, 1979) PL 480 Project no Inn FS-66. pp. 85.

Rao RV, Shashikala S. 2003. Assessment of growth rate, basic density and heart wood content in selected teak clones of CSO, Thithimathi in Karnataka state, India. In: International Conference on Quality Timber Products of Teak from Sustainable Forest Management, 2-5 December 2003, KFRI, Kerala, India (abstracts). p. 57.

Rao RV, Shashikala S, Sreevani P, Kothiyal V, Sharma CR, Lal P. 2002. Within tree variation in anatomical properties of some clones of *Eucalyptus tereticornis* Sm. *Wood and Science Technology*, **36**(3): 271−285.

Rao BSS, Rao RV. 1978. Variation in length of vertical elements within one tree of *Betula pubercens* Ehrh. *Journal of Indian Academy of Wood Science*. **9**(2): 105−110.

Reck S. 1974. Growth and wood characteristics in clones of *Populus trichocarpa* grown in West Germany and their significance for selection. IUFRO meeting, Stockholm, Sweden.

Veenin T, Fujita M, Nobuchi T, Siripatanandilok S. 2005. Radial variations of fffanatomical characters and specific gravity in *Eucalyptus camaldulensis* clones. *IAWA Journal*, **26**(3): 353−361.

Zobel B. 1965. Inheritance of fibre characteristics and specific gravity in hardwoods- A review. In: IUFRO Proceedings of the Meeting of Section. 41 Meet, Melbourne, Australia. p. 13.

Zobel BJ, Buijtenen van JP. 1989. *Wood variation: its causes and control*. Berlin: Springer-Verlag, p. 363.